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16. Abstract

The research consists of the analysis of the process capability of portland cement concrete. The study was made on the basis of 1) a statistically designed experiment, from which parameters were obtained for various specification requirements of concrete; and 2) historical data, consisting of measurements obtained without random sampling.

The statistically designed experiment gives information in regard to variances due to material, sampling and testing, for aggregates and portland cement concrete pavement. For historical data no analysis of variance has been done. In addition, information in regard to skewness and kurtosis are of special interest, for studies in regard to the nature of distributions. Statistical parameters have been obtained for aggregates, on the basis of percent passing and percent retained. Such analysis indicates the underlying causes of variance, and thus aids in better control of aggregate production and utilization.

A study has been made of conformal index, which can be considered as a measure of the capability of construction process, and indicates the deviations from the approved job-mix formula, unlike the standard deviation which gives the measure of the deviations from the mean of a population.

A study has been made on the variations of coarse aggregate used in the concrete and as obtained from the pavement. The basis of the analysis is the Wilcoxon matched-pairs signed-ranks test.

A comparison has also been made of normal project sampling and random sampling. The statistical parameters obtained by the two methods of sampling on the same project shows the variations possible by different methods of project control.

17. Key Words

Statistical Analysis, Random Sampling, Analysis of Variance, Standard Deviation, Coefficient of Variation, Skewness, Kurtosis, Average Deviation, Conformal Index, Portland Cement Concrete, Historical Data, Concrete Cores, Thickness

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IMPLICATIONS OF STATISTICAL QUALITY CONTROL

OF

PORTLAND CEMENT CONCRETE

Research Project No. HPR-1-12(152)

Final Report

by

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IMPLICATIONS OF STATISTICAL QUALITY CONTROL

OF PORTLAND CEMENT CONCRETE

George F. D. Gonsalves & John F. Eisenberg
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ABSTRACT

The research consists of the analysis of the process capability of portland cement concrete. The study was made on the basis of 1) a statistically designed experiment, from which parameters were obtained for various specification requirements of concrete; and 2) historical data, consisting of measurements obtained without random sampling. A comparison of the parameters obtained by the two methods shows the effect of random sampling, and the variation of parameters.

The statistically designed experiment gives information in regard to variances due to material, sampling and testing, for aggregates and portland cement concrete pavement. For historical data no analysis of variance has been made. In addition, information in regard to skewness and kurtosis are of special interest, for studies in regard to the nature of the distributions. Statistical parameters have been obtained for aggregates, both on the basis of percent passing and percent retained. Such analyses indicate the underlying causes of variance, and thus aids in better control of aggregate production and utilization.

A study has been made of conformal index, which is a measure of the capability of the construction process to adhere to the job-mix formula. It is unlike the standard deviation which gives a measure of the deviations from the mean of the construction process. The difference between the standard

deviation and conformal index is a measure of difference between the product possible and the product obtained. Conformal index values have been obtained for the statistically designed experiment.

A study has been made on the variations of coarse aggregate used in the concrete and as obtained from the pavement. The basis of the analysis is the Wilcoxon matched-pairs signed-ranks test.

A comparison has also been made of normal project sampling and random sampling. The statistical parameters obtained by the two methods of sampling on the same project, shows the variations possible by different methods of project control.

KEYS WORDS

Statistical analysis, random sampling, analysis of variance, standard deviation, co-efficient of variation, skewness, kurtosis, average deviation, conformal index, portland cement concrete, historical data, concrete cores, pavement thickness, aggregates, variability, Wilcoxon matched-pairs signed-ranks test.

INTRODUCTION

Portland cement concrete is hetrogeneous mixture of supposedly inert crushed rock or gravel and sand held together by a hardened paste of cement. The normal technology of cement concrete uses water and various additives to prepare a properly proportioned plastic mass, which can be molded into any desired shape or size. Upon hydration of the cement, portland cement concrete becomes a hardened cohesive mass, capable of withstanding great pressures. Because of its ease of handling and easy technology, concrete has become the preferred material in the construction of highways, bridges and dams, and additionally in the most artistic and decorative of structures. Its popularity has been further enhanced, for, when used in combination with steel reinforcement, it yields a product of great structural strength. The extensive use of portland cement concrete is attested to by the fact that the production of cement in the United States reached an all time high of 87 million short tons in 1973. The production of twenty-two leading countries in the world is in excess of 730 million short tons.

Great progress has been made in the production of cement and the technology of production and placement of concrete. Practically all development has taken place in the last one hundred years - from an undeveloped state of control and practically no use of reinforcement. Current concrete control and methodology includes, weigh batching, air-entrainment and additives for water reducing, accelerating and retarding concrete set, workability, dampproofing, gas-forming, and a variety of cements, aggregates, polymers and pozzolans and reinforcement. A closely controlled mixture of component materials will yield a product of predetermined quality and variability.

Specifications for concrete are based on:

a) Property specifications, where the acceptability of concrete is based on the properties of the various components making up the mix, and the properties of the resulting concrete tested in the laboratory.

b) Recipe specifications, where the acceptability of concrete is based on the properties of the various components making up the mix, and their proportions.

The properties of concrete and its various components are determined on the basis of various test methods, which form part of materials manuals of testing and control procedures. However results of tests indicate a variation under existing methods of control and technology. These variations can be attributed to various random causes, but essentially can be classified as material, sampling, and testing variances. The nature of material sources along with the actual technological process and with variations brought about by sampling and testing are prime causes of the variability problem.

Statistics is a subject dealing with the uncertainty of the accuracy on sets of observations, and helps in understanding and interpreting these results and also in their generalization. This research is therefore 1) a controlled experiment, the results of which are statistically analyzed, and 2) an analysis of historical data for the purpose of comparison with the controlled experiment.

OBJECTIVES OF RESEARCH

The overall objectives of the research are to statistically determine the quality of reasonably good portland cement concrete pavement, constructed by modern construction methods and a competent contractor. This would give statistically determined quality parameters for all measured characteristics of the acceptable materials and construction. A separate part of the study will consist of the statistical analysis of historical data. The development of the realistic parameters will result in the preparation of realistic specifications and will insure equitable risks to both the buyer and seller. This will result in reasonable contracting costs, and also a minimum risk of accepting defective material which ultimately will reduce expenditures for maintenance or corrective procedures.

The first part of the research program is a statistically designed experiment to determine normal variations in characteristics of concrete materials and construction. This information will enable contracting agencies to:

a) Prepare specifications for materials and construction that are reasonably acceptable.

b) Analyze testing and sampling procedures and to determine their capability.

c) Develop a sampling schedule that is statistically sound, with known risks to the buyer and seller.

d) Place all process control responsibilities on the contractor and furnish incentives for the use of superior and competitive construction methods, thus ultimately resulting in maximum savings to the contracting agencies.

e) To use the information obtained in this research as a guide in drafting specifications for portland cement concrete pavement, and to develop a rational basis for making price adjustments for defective materials or concrete.

The second part of the research is a study of historical data consisting of measurements on existing pavements, which will indicate the variation where no statistical methods were used.

General: All field operations were executed completely independent of normal job control, for the purpose of this study. All normal field control was made by existing procedures. The two crews worked independently to preclude any bias in sampling. The program was intended to measure variations expected in good construction, and considerations concerning the size of the project, the quality level of the design and the equipment used were important considerations in selecting the project.

APPROACH TO RESEARCH AND DATA COLLECTION

I. Research Approach:

The overall Research Approach consists of:

A. Statistically designed experiments to obtain unbiased data on currently specified measurements made in connection with the production of concrete aggregates, and the placement of portland cement concrete pavement. To satisfy this objective the following evaluations were made:

a) The determination of statistical parameters of aggregates, concrete and portland cement concrete pavement.

b) The determination of sampling, testing and material variances.

c) The analysis of the proportions of aggregate in the concrete pavement. This will provide us with a measure of the relationship between the product specified and the product obtained.

d) The evaluation and feasibility of using these parameters in the drafting of statistical specifications, with acceptance plans and a price adjustment that is equitable to all concerned. The basis of these plans will depend on the determination of the critical characteristics of what constitutes good and poor material.

e) The implementation of these specifications in actual construction, will allow their reviewing and updating, depending on their actual performance.

B. Historical Data will be evaluated to study the variations on completed projects and to make comparisons with data obtained under item A above. Random sampling techniques were not used on these projects.

II. Data Collection:

A. The data for statistically designed experiments was collected on the basis of the recommendations made under the program for aggregates and portland cement concrete in "The Statistical Approach to Quality Control in Highway Construction" U. S. Department of Commerce, Bureau of Public Roads - April 1965. All sampling and testing procedures were generally in accordance with Arizona Department of Transportation procedures, except where the requirements of replication were met by the recommendations in the reference above. The placement of concrete was made by dump trucks and a CMI slip form paver. The sampling of concrete was done in front of the CMI paver by stratified random sampling in the plastic concrete. In order to obtain corresponding data on aggregates, samples were obtained from the belt to represent the concrete sampled. A portion of the concrete sampled was also washed to obtain the gradation of coarse aggregate in the concrete.

The following characteristics of concrete and aggregate were determined:

a) Gradation

b) Sand Equivalent

c) Percent Air

d) Slump

e) Concrete Temperature

f) Air Temperature

g) Compressive strength after curing for 28 days.

Cores were obtained from the concrete pavement at the same location where the plastic concrete was sampled. A determination was made of the 28-day compressive strength and the length of the cores was measured.

B. Historical data from files on completed concrete projects was similarly obtained. Controlled statistical sampling techniques were not employed on these projects. The statistical analysis is therefore used for purposes of comparison and the study of trends in parameters. The aggregate samples were generally obtained from stockpiles, and their numbers do not correspond to the number of cylinders. The following projects were used for statistical analysis of portland cement concrete.

ITEM NO.	PROJECT NO.	NAME OF PROJECT
1	I-10-1(35)	Brenda-Hope T. I.
2	I-10-2(18)	Ehrenberg-Phoenix Hwy (Yuma Co. Line-Burnt Well)
3	I-10-2(19)	Ehrenberg-Phoenix Hwy (Brunt Well-Tonopah)
4	I-17-2(35)	Cordes Jct-Flagstaff (Munds Park-Flagstaff Airport)
5	I-40-1(20)	Topock-Kingman Hwy (Havasu T.I.-Franconia)
6	I-40-2(59)	Kingman-Ash Fork (Juniper Mtn.-Chino)
7	F-22-3-513	Phoenix-Globe Hwy (Mesa Drive-Lindsay Road)
8	EHS-T-980	Phoenix Metropolitan Area (16th Street and Northern)
9	BR-S-371(5)	Buckeye-Phoenix Hwy (Agua Fria River Bridge-Class A)
10	BR-S-371(5)	Buckeye-Phoenix Hwy (Agua Fria Class D Concrete)

All concretes analyzed are Class A concretes, except for item 10 above, which is a Class D concrete.

PROJECT INVESTIGATED

Project I-17-2(35), Cordes Juction-Flagstaff (Munds Park-Flagstaff Airport) was selected for the statistically designed experiment. The location is shown in Figure 1-B. The project had about 200,000 square yards of portland cement concrete pavement, 8" thick, which was placed by a CMI slip form paver. The concrete was placed to a width of 24 feet, and approximately 5,000 lineal feet of pavement was placed in one day.

SPECIFICATIONS FOR PORTLAND CEMENT CONCRETE PAVEMENT

The specifications given below are the part of the requirements for portland cement concrete, that are relevant to the research done on Project

No. I-17-2(35) Cordes Junction-Flagstaff (Munds Park-Flagstaff Airport).

Gradation:

Fine Aggregate:

Passing 3/8" Sieve	100%	
Passing No. 4 Sieve	95 - 100%	
Passing No. 16 Sieve	45 - 80%	
Passing No. 50 Sieve	10 - 30%	
Passing No. 100 Sieve	2 - 10%	
Passing No. 200 Sieve	0 - 4%	
Coarse Aggregate No. 1		Specification Change
Passing 2-1/2" Sieve	100%	
Passing 2" Sieve	95 - 100%	
Passing 1-1/2" Sieve	35 - 70%	50 - 80%
Passing 1" Sieve	1 - 15%	5 - 20%
Passing 1/2" Sieve	0 - 5%	
Coarse Aggregate No. 2		
Passing 1-1/2" Sieve	100%	
Passing 1" Sieve	95 - 100%	
Passing 1/2" Sieve	25 - 60%	
Passing No. 4 Sieve	0 - 10%	
Passing No. 8 Sieve	0 - 5%	
Composite of Coarse Aggregates No. 1 and No. 2		
Passing 2-1/2" Sieve	100%	
Passing 2" Sieve	95 - 100%	

Composite of Coarse Aggregates No. 1 and No. 2 (Continued)

Passing 1" Sieve	35 - 70%
Passing 1/2" Sieve	10 - 30%
Passsing No. 4 Sieve	0 - 5%

The 1-1/2" and 1" screen specification for coarse aggregate No. 1 were changed about the middle of the project, however, the composite coarse aggregate was to conform to the requirements indicated above.

The concrete was designed with a cement factor of six sacks per cubic yard, with an air requirement or 4-7% and a slump of 1-3 inches. The temperature of concrete was not to exceed 90^{o}F; and the air temperature was to be not less than 40^{o}F. Concrete operations were not to be started unless the ascending air temperature was at least 35^{o}F.

LABORATORY TEST DATA AND STATISTICAL ANALYSIS

I. Laboratory Test Data

The test results are divided into two groups as designed experiments and historical data. For the studies reported herein a total of about 6,700 measurements were made under designed experiments and about 13,000 measurements under historical data. Under the designed experiments an analysis was generally made to determine the variance caused by material, sampling and testing. This will help the engineer in assessing the efficiency of present procedures. No such analysis was made under historical data. It may also be pointed out, that these data were not obtained by random sampling.

II. Statistical Analysis

A. Statistical Analysis: A statistical analysis was made of all data obtained under designed experiments and historical data. The results are given in Tables 1-A to 12-A and Figures 2B to 11B for designed experiments. For historical data the results are given in Tables 13-A to 42-A and Figures 12B to 31B.

a) Designed Experiment

The statistical analysis was divided into the following categories for the designed experiments. 1) Analysis of variance of aggregates, and portland cement concrete pavement - Tables 1-A to 12-A and Figures 2B to 11B. 2) A study of conformal index - Tables 43-A to 47-A. 3) Comparison of aggregates and portland cement concrete pavement with statistical and specification requirements - Tables 39-A to 44-A. 4) Comparison of aggregate at the batch plant and in the pavement - Table 54-A to 56-A.

b) Historical Data: A statistical analysis was made on portland cement concrete from ten projects - Tables 13-A to 42-A and Figures 12-B to 31-B.

B. Conformal Index: An investigation was made in regard to conformal index (C. I.) which is comparable to the standard deviation and defined as the root mean square of deviations from the target value and not from the arithmetic mean as in standard deviation. A study of both standard deviation and conformal index allows a comparison of the construction process and the project target value. The relationship between standard deviation and conformal index is given by the following:

$$\text{Conformal Index (C. I.)} = \sqrt{\frac{(n-1)\ \sigma^2 + nd^2}{n}}$$

Where σ is the standard deviation and d is the average deviation of the measurements from the target value. n is the total number of measurements (1)*. All conformal index values were calculated by the above formula.

COST ANALYSIS

An analysis of cost on the project has been made, with reference to labor, laboratory testing, travel, equipment rental and miscellaneous expenditures. Table 1 indicates a cost per square yard (0.836 square meters) of pavement is 37.1 cents. The largest portion of 27.0 cents per square yard (0.836 square meters) was incurred on salaries and payroll additives of personnel. The cost of laboratory testing was 4.9 cents per square yard (0.836 square meters) of pavement. Travel, equipment rental and miscellaneous expenditure accounted for 5.2 cents per square yard (0.836 square meters).

The relationship between the frequency of testing and material production, is shown in Table 2. Fifty test locations were used. Duplicate testing was done, giving a total of 100 to 400 test samples. Each test represented 83.3 to 333.3 cubic yards (63.7 to 254.8 cubic meters) of concrete or 666.7 cubic yards (509.7 cubic meters) per test location.

TABLE 1

Cost Analysis

	COST-DOLLARS	COST %	COST PER SQ. YD. OF PAVEMENT-DOLLARS
Labor	40,319.86	72.7	0.2700
Laboratory	7,304.00	13.2	0.0489
Travel	3,569.73	6.4	0.0239

* Numbers in parenthesis refer to references, at the end of this report.

TABLE 1 (continued)

Cost Analysis

	COST-DOLLARS	COST %	COST PER SQ. YD. OF PAVEMENT-DOLLARS
Equipment Rental	2,526.47	4.6	0.0169
Miscellaneous	1,748.92	3.1	0.0117
TOTAL	55,468.98	100.0	0.3714

TABLE 2

Relationship Between Testing and Materials Production

Type of Test	Total Number of Tests	Number of Test Locations	Average Size of Pavement Represented Per Test Sq Yds	Per Test Cu Yds	Per Location Sq Yds	Per Location Cu Yds
Gradation Aggregates						
Coarse #1	200	50	750	166.7	3000	666.7
Coarse #2	200	50	750	166.7	3000	666.7
Fine	200	50	750	166.7	3000	666.7
Sand Equivalent	200	50	750	166.7	3000	666.7
Portland Cement Concrete						
% Air	200	50	750	166.7	3000	666.7
Slump	200	50	750	166.7	3000	666.7
Concrete Temperature	200	50	750	166.7	3000	666.7
Air Temperature	200	50	750	166.7	3000	666.7
Concrete Compressive Strength	400	50	375	83.3	3000	666.7
Concrete Density	200	50	750	166.7	3000	666.7
Cores-Compressive Strength	100	50	1500	333.3	3000	666.7
Cores-Length	100	50	1500	333.3	3000	666.7

DISCUSSION AND ANALYSIS OF TEST RESULTS

I. Analysis of Variance:

The relative variances due to material (σ_m^2), sampling (σ_s^2) and testing (σ_t^2) are given in Tables 3 to 9, for aggregates and portland cement concrete pavement.

TABLE 3

Coarse Aggregate #1 - Components of Variance

Relative Percent Variance

Sieve Size	Percent Passing			Percent Retained		
	σ_m^2	σ_s^2	σ_t^2	σ_m^2	σ_s^2	σ_t^2
2"	27.1	5.7	67.2	25.3	0	74.7
1-1/2"	66.1	8.1	25.8	59.2	14.8	26.0
1"	86.1	7.1	6.8	75.0	0	25.0
3/4"	82.5	8.5	9.0	83.8	7.7	8.5
1/2"	76.2	11.3	12.5	82.2	8.7	9.1
No. 4	58.0	19.9	22.1	84.0	11.1	4.9

TABLE 4

Coarse Aggregate #2 - Components of Variance

Relative Percent Variance

Sieve Size	Percent Passing			Percent Retained		
	σ_m^2	σ_s^2	σ_t^2	σ_m^2	σ_s^2	σ_t^2
1"	58.8	14.1	27.1	65.3	5.6	29.1
3/4"	68.6	25.2	6.2	67.8	22.8	9.4
1/2"	75.9	20.2	3.9	75.6	10.4	14.0

TABLE 4 (Continued)

Coarse Aggregate #2 - Components of Variance

Relative Percent Variance

Sieve Size	Percent Passing			Percent Retained		
	σ_m^2	σ_s^2	σ_t^2	σ_m^2	σ_s^2	σ_t^2
3/8"	79.6	17.5	2.9	79.1	4.9	16.0
1/4"	89.0	8.3	2.7	72.8	22.8	4.4
No. 4	88.0	7.1	4.9	88.9	8.4	2.7
No. 8	83.1	8.1	8.8	87.5	7.8	4.7

TABLE 5

Composite of Coarse Aggregates #1 & #2 - Components of Variance

Relative Percent Variance

Sieve Size	Percent Passing			Percent Retained		
	σ_m^2	σ_s^2	σ_t^2	σ_m^2	σ_s^2	σ_t^2
2"	27.3	5.5	67.2	22.0	12.0	66.0
1-1/2"	66.0	7.6	26.4	59.2	14.0	26.8
1"	85.4	7.3	7.3	74.4	1.0	24.6
3/4"	79.5	13.9	6.6	77.3	11.8	10.9
1/2"	79.9	15.9	4.2	79.7	4.8	15.5
3/8"	81.9	14.4	3.7	79.4	4.9	15.7
1/4"	84.8	10.0	5.2	72.7	23.0	4.3
No. 4	74.4	14.0	11.6	86.8	10.4	2.8
No. 8	62.8	25.6	11.6	77.2	11.2	11.6

TABLE 6

Fine Aggregate - Components of Variance

Relative Percent Variance

Sieve Size	Percent Passing			Percent Retained		
	σ_m^2	σ_s^2	σ_t^2	σ_m^2	σ_s^2	σ_t^2
No. 4	62.3	3.8	33.9	68.8	0	31.2
No. 8	78.9	0.1	21.0	76.0	0	24.0
No. 10	79.8	0.1	20.1	50.0	20.3	29.7
No. 16	85.0	0	15.0	73.5	13.8	12.7
No. 30	82.9	1.9	15.2	39.8	25.5	34.7
No. 40	76.9	1.0	22.1	85.1	5.2	9.7
No. 50	59.0	2.7	38.3	85.2	5.2	9.6
No. 100	56.4	3.8	39.8	71.9	5.2	22.9
No. 200	50.0	3.3	46.7	43.3	16.7	40.0

TABLE 7

Composite of Coarse & Fine Aggregate Components of Variance

Relative Percent Variance

Sieve Size	Percent Passing			Percent Retained		
	σ_m^2	σ_s^2	σ_t^2	σ_m^2	σ_s^2	σ_t^2
2"	22.0	12.0	66.0	22.0	12.0	66.0
1-1/2"	65.7	7.2	27.1	59.2	14.0	26.8
1"	85.4	7.2	7.4	74.5	1.0	24.5
3/4"	79.7	13.6	6.7	77.3	11.7	11.0

TABLE 7 (Continued)

Composite of Coarse & Fine Aggregate Components of Variances

Relative Percent Variance

Sieve Size	Percent Passing			Percent Retained		
	σ_m^2	σ_s^2	σ_t^2	σ_m^2	σ_s^2	σ_t^2
1/2"	80.2	15.4	4.4	79.9	5.0	15.1
3/8"	82.4	13.9	3.7	77.8	5.5	16.7
1/4"	84.2	10.4	5.4	69.3	24.8	5.9
No. 4	69.7	19.3	11.0	86.0	8.5	5.5
No. 8	77.6	0.5	21.9	79.3	1.8	18.9
No. 10	78.9	0.4	20.7	60.9	17.4	21.7
No. 16	84.4	0.2	15.4	73.8	14.3	11.9
No. 30	82.6	1.9	15.5	40.6	25.0	34.4
No. 40	76.1	0.8	23.1	84.3	5.9	9.8
No. 50	57.5	2.5	40.0	84.4	4.5	11.1
No. 100	53.3	6.7	40.0	72.0	4.0	24.0
No. 200	50.0	0	50.0	40.0	20.0	40.0

TABLE 8

Sand Equivalent - Components of Variance

Relative Percent Variance

σ_m^2	σ_s^2	σ_t^2
72.5	7.1	20.4

TABLE 9

Portland Cement Concrete Pavement - Components of Variance

Type of Test	σ_m^2	σ_s^2	σ_t^2
% Air	77.4	1.1	21.5
Slump	86.1	5.6	8.3
Concrete Temp.	91.8	1.0	7.2
Compr. Strength	85.0	-1.8	16.8
Concrete Density	35.3	13.7	51.0

The analysis of variance indicates that the major part of the total variance is due to material variance; sampling methods contribute the least variance. The relative percent variances are given in Table 3 to 9. The largest variances took place in coarse aggregate #1. The finer aggregates gave smaller variances. It is possible that larger aggregates require larger samples for testing. It should be pointed out that the tests were made by a group of trained technicians. Had a broad spectrum of technician capability been utilized, the testing variance would have been larger.

II. Variability of Aggregates

The standard deviations of aggregates have been obtained on the basis of percent passing a particular sieve, and the percent retained on each individual sieve of the entire nest of sieves in the standard test for gradation of aggregates. The two calculations help to understand the underlying cause of variance. The percent passing a particular sieve indicates only the material larger or smaller than a particular sieve size but not the relative distribution of the various sizes. The results are given in Tables 1-A to 10-A and 13-A to 32-A and Figures 2B to 31B. It may be seen that on the basis of percent passing, the variations on any one sieve, have a cumulative effect on the variations on all smaller sieve sizes. On the basis of percent retained, the variations of material do not directly affect the subsequent sieves. A similar study was made in Statistical Analysis of Asphaltic Concrete Production and Placement - Project I-8-1(43) Ligurta-Antelope Hill (2).

The standard deviations indicate that variations for larger aggregates are greater than that of smaller aggregates. It is also possible that larger test samples are required than called for in the standards. Similarly the larger the fraction retained on any particular screen, the larger is the variance generally. The standard deviations are also affected by conditions of truncation, which largely characterize the first and last sieves in a gradation, and to a lesser extent all other sieves.

III. Variability of Portland Cement Concrete

The distribution characteristics generally indicate wider variations when random sampling is used as compared to present methods of sampling. The standard deviation for compressive strength was 601.9 psi (4.15 N/mm^2) for the designed experiment. For the historical data the standard deviations varied from 327.2 to 576.6 psi (2.25 to 3.97 N/mm^2). Similarly the coefficient of variation for compressive strength was 13.8 on the designed experiment and on historical data (ten projects) it varied from 10.3 to 15.1.

IV. Nature of Distributions

In order to understand the general nature of distributions, additional factors such as skewness and kurtosis have been obtained. Attempts were made to discard outliers. However, no major benefit was realized. The results tabulated are therefore generally representative of all test measurements. The values of skewness and kurtosis indicate that the gradation of aggregate distributions are not normal. The characteristics of portland cement concrete, however, tend to be normally distributed. In general it may be stated that the value of normal distribution has been overemphasized. A purely theoretical concept has failed to take into consideration the risks that could be run in the practical operations of materials and construction. It is suggested that in actuality there is no strictly randomly operating process or series of identical lots. The series of lots that come up for inspection have a variability due to an inherent process of variation characterized in the nature of all material. The values of skewness and kurtosis can greatly help in assessing deviations from normal distribution, and in the preparation of meaningful specifications. The distributions are in keeping with the capability of the construction process and the uniformity of the pit, along with the accuracy of testing and sampling methods.

A comparison was also made of actual frequency distributions with statistical requirements, as given in Tables 48-A to 53-A. The variations are the largest with coarse aggregate, again indicating a probability of inadequate sample sizes. The comparison was made with reference to normal distribution, and the results indicate that normality is not generally obtained.

V. Conformal Index

A comparison of conformal index and standard deviation has been made in Tables 43-A to 47-A, to study the conformity of the material produced with the target value. If the product obtained is the same as the job-mix formula, the two values are identical. The divergence of conformal index from the standard deviation is a measure of the difference between the product obtained and the target value. Calculations have not been made for coarse aggregate #1 in view of changes of specification. However, the results of the composite of coarse aggregates #1 and #2 can be used for comparison. It should also be pointed out that considerations of variance due to sampling and testing should be taken into account.

A comparison of standard deviation and conformal index has been made for a) Corase Aggregate #2, b) Composite of Coarse Aggregate #1 and #2, c) Fine Aggregate, d) Composite Aggregate of Coarse and Fine Materials and e) the requirements of air content and slump of portland cement concrete for pavement. The values of standard deviation and conformal index, are related to each other on the basis of the target value and the arithmetic mean. It has no relationship with specification limits. Thus a product which passes the specification may have a conformal index which is higher than that where part of the product is out of the specification. A study of conformal index should be made in conjunction with standard deviation, target value and specification limits, in order to understand the meaning of these values.

A study was also made in regard to the number of test samples not meeting the specification requirements. The results are given in Tables 48-A to 53-A. The large disparity between random sampling and normal project control is shown mainly in larger aggregates. The largest difference occurs in the case of coarse aggregate #1. Coarse aggregate #2 has a smaller number of samples outside specifications. All samples of fine aggregate met the specification requirements. It is suggested that the size of test samples needs investigation. In the case of portland cement concrete only the entrained air was difficult to control. All other requirements of the project specification were completely met.

VI. Comparison of Portland Cement Concrete as Batched and in Pavement

A study was made in regard to the differences between the product batched and that obtained in the pavement. For this study the gradation of coarse aggregate from both sources was determined. Table 54-A gives the gradation of the aggregate in the concrete and as obtained from the belt. A statistical analysis of coarse aggregate from the concrete is given in Tables 55-A to 56-A. The statistical values are generally in keeping with those of the composite of coarse aggregates #1 and #2 as given in Tables 5-A and 6-A.

A comparison was also made on the coarse aggregates obtained from the pavement concrete and that from batching plant, on the basis of the Wilcoxon matched-pairs signed-ranks test. The results are given in Table 10. The probabilities obtained are for a two-tailed test. The probabilities are generally very low, indicating excessive variations.

TABLE 10

Results of Wilcoxon Matched-Pairs Signed-Ranks

Test on Aggregates from Pavement and Batch Plant

Sieve Size	Probability % Retained	% Passing	Number of Samples
2"		0.763	50
1-1/2"	0.002	0.003	50

TABLE 10 (Continued)

Results of Wilcoxon Matched-Pairs Signed-Ranks

Test on Aggregates from Pavement and
Batch Plant

Sieve Size	Probability % Retained	% Passing	Number of Samples
1"	0.005	0.0	50
3/4"	0.128	0.0	50
1/2"	0.050	0.0	50
3/8"	0.001	0.0	50
1/4"	0.000	0.0	50
No. 4	0.000	0.0	50

VII. Historical Data

Conrol on these projects was not done by random sampling techniques. The ten projects investigated were also divided into three groups to represent the varying specifications for aggregate gradation called for in the contract.

Group 1

a) Project I-10-2(35) Brenda-Hope T.I.

b) Project EHS-T-980(22) Phoenix Metropolitan Area (16th Street and Northern)

Group 2

a) Project I-10-2(18) Ehrenberg-Phoenix (Yuma Co. Line-Burnt Well)

b) Project I-10-2(19) Ehrenberg-Phoenix (Burnt Well-Tonopah)

c) Project F-022-3-513 Phoenix-Globe (Mesa Drive-Lindsay Road)

d) Project BR-S-371(5) Buckeye-Phoenix (Agua Fria River Bridge)

Concrete Class A

e) Project BR-S-371(5) Buckeye-Phoenix (Agua Fria River Bridge)

Class D Concrete

Group 3

a) Project I-17-2(35) Cordes Jct.-Flagstaff (Munds Park-Flagstaff Airport)

b) Project I-40-1(20) Topock-Kingman (Havasu T.I.-Franconia)

c) Project I-40-2(59) Kingman-Ash Fork (Juniper Mountain-Chino)

The standard deviations for the three groups indicate a measure of variation of statistical parameters, both on the basis of percent passing and percent retained.

The variations of standard deviations for concrete qualities are shown below in Tables 11 and 12. These results are to be studied in conjunction with the skewness and kurtosis of the distributions to understand the complete nature of distributions. There is a wide range of standard deviations, and these results are not inclusive of all values. The values of standard deviation for air content, slump and compressive strength are generally lower than those obtained for the controlled experiment done with random sampling. With random sampling the standard deviation is 0.97% for air content, 0.60 inches (1.52 cm) for slump, and 601.9 psi (4.15 N/mm^2) for 28 day compressive strength.

TABLE 11

Variations of Standard Deviations of Portland Cement Concrete - Historical Data

Item of Work	Range of Standard Deviations
% Air	0.54 to 1.19
Slump inc.	0.31 to 0.68
(Slump cms)	(0.79 to 1.73)
Concrete Temp. °F	4.26 to 11.38
(Concrete Temp. °C)	(2.37 to 6.32)
Air Temp. °F	7.92 to 16.09
(Air Temp. °C)	(4.40 to 8.94)
28 day Strength-PSI	327.23 to 576.62
(28 day Strength-N/mm^2)	(2.26 to 3.98)
7 day Strength-PSI	296.91 to 482.89
(7 day Strength N/mm^2)	(2.05 to 3.33)

TABLE 12

Variations of Standard Deviations of Aggregates for Portland Cement Concrete

Historical Data

Sieve Size	Range of Standard Deviations	
	Percent Passing	Percent Retained
3/4"	0.65 - 2.45	0.99 - 2.45
1/2"	2.30 - 6.14	1.82 - 6.07
3/8"	1.20 - 3.84	1.23 - 2.32
1/4"	0.95 - 1.64	2.13 - 3.60

TABLE 12 (Continued)

Variations of Standard Deviations of
Aggregates for Portland Cement Concrete

Historical Data

Sieve Size	Range of Standard Deviations Percent Passing	 Percent Retained
No. 4	0.50 - 2.38	0.30 - 6.91
No. 8	0.70 - 1.78	0.48 - 0.97
No. 16	0.83 - 2.55	0.46 - 2.49
No. 30	0.96 - 2.28	0.41 - 1.20
No. 50	0.64 - 1.64	0.30 - 2.29
No. 100	0.32 - 0.91	0.39 - 1.29
No. 200	0.17 - 0.47	0.25 - 0.63

VIII. Comparison between Random and Project Sampling

Two sets of test samples were taken from the project. One set was taken by project personnel on the basis of representative sampling. The second set of samples were taken by a separate crew of technicians, using random sampling methods. The two groups worked independently, in order to preclude any bias in sampling. Tables 1-A to 12-A give the statistical analysis of aggregates and portland cement concrete, on the basis of random sampling. Tables 57-A to 67-A give the corresponding statistics, with representative sampling. The results are also plotted in Figures 32-B to 61-B for aggregates and portland cement concrete. The normal distribution curves have been plotted along with the specification limits, to show the product planned and the actual product obtained with reference to the two methods of sampling.

The results of statistical analysis are compiled in Table 13, for ease of comparison of values of the deviations from target value and the differences between arithmetic means and standard deviations, obtained by the methods of random and representative sampling. The deviations from target value are generally larger with the larger-sized aggregates. The largest deviations are with coarse aggregate No. 1. It is suggested that the probability is large that the size of samples tested was not adequeate. The deviations from target value of the arithmetic means are random variables and may be positive or negative. The deviations from target value with coarse aggregate No. 2 and fine aggregate are smaller than those of coarse aggregate No. 1. The deviations are generally larger with representative sampling. The deviations from target value for the total composite are smaller, compared to coarse aggregate No. 1, since the three individual aggregates were proportioned to give the desired aggregate gradation. The deviations are again random and can be either positive or negative.

The arithmetic means for larger aggregates, obtained with random sampling are larger than those obtained with representative sampling. For fine aggregate, the values are larger with representative sampling. This is also the case with standard deviations. These values are also randomly distributed (Figures 54-B to 61-B).

The statistical parameters for concrete qualities of percent air and slump indicate lower means than the target values. The differences between means and standard deviations for random and representative sampling are random and can be positive or negative.

TABLE 13

Comparison Between Project and Random Sampling - Percent Passing

Aggregate Type	Sieve Size	Target Value	Random Sampling Arithmetic Mean	Random Sampling Standard Deviation	Project Sampling Arithmetic Mean	Project Sampling Standard Deviation	Deviation of Mean From Target Value Random Sampling	Deviation of Mean From Target Value Project Sampling	Difference Between Arithmetic Means	Difference Between Standard Deviations
Coarse	2"	97.5	98.46	2.26	96.05	1.91	0.96	-1.45	2.41	0.35
Aggregate #1	1-1/2"	65.0	75.84	8.80	69.33	7.44	10.84	4.33	6.51	1.36
	1"	12.5	24.50	12.50	17.18	7.66	12.00	4.68	7.32	4.84
Coarse	1"	97.5	96.46	1.88	96.00	1.88	-1.04	-1.50	0.46	0.0
Aggregate #2	1/2"	42.5	47.13	7.49	43.50	6.91	4.63	1.00	3.63	0.58
	No. 4	5.0	6.10	2.46	3.44	1.88	1.10	-1.56	2.66	0.58
	No. 8	2.5	2.77	1.11	1.34	0.75	0.27	-1.16	1.43	0.36
Fine	No. 4	97.5	98.08	1.03	98.22	0.79	0.58	0.72	-0.14	0.24
Aggregate	No. 16	62.5	61.85	5.21	60.82	6.16	-0.65	-1.68	1.03	-0.95
	No. 50	20.0	16.13	1.51	16.64	1.86	-3.87	-3.36	-0.51	-0.35
	No. 100	6.0	6.18	0.88	6.62	1.27	0.18	0.62	-0.44	-0.43
	No. 200	2.0	2.81	0.54	3.20	0.89	0.81	1.20	-0.39	-0.35
Composite	2"	97.5	99.23	1.13	98.04	0.91	1.73	0.54	1.19	0.22
of Coarse	1"	52.5	60.52	6.49	56.67	3.61	8.02	4.17	3.85	2.88
Aggregates	1/2"	20.0	25.91	5.02	21.87	3.89	5.91	1.87	4.04	1.13
1 and 2	No. 4	2.5	4.23	2.00	1.79	1.13	1.73	0.71	2.44	0.87

Table 13 (Continued)

Comparison Between Project and Random Sampling - Percent Passing

Aggregate Type	Sieve Size	Target Value	Random Sampling Arithmetic Mean	Random Sampling Standard Deviation	Project Sampling Arithmetic Mean	Project Sampling Standard Deviation	Deviation of Mean From Target Value Random Sampling	Deviation of Mean From Target Value Project Sampling	Difference Between Arithmetic Means	Difference Between Standard Deviations
Total	2"	98.5	99.55	0.71	98.85	0.54	1.05	0.35	0.70	0.17
Composite	1"	71.78	76.56	3.85	74.27	2.04	4.78	2.49	2.29	1.81
Aggregate	1/2"	52.48	56.00	2.98	53.63	2.15	3.52	1.15	2.37	0.83
	No. 4	41.07	42.34	1.20	41.05	1.07	1.27	-0.02	1.29	0.13
	No. 16	25.37	25.12	2.12	24.89	2.52	-0.25	-0.48	0.23	-0.40
	No. 50	8.12	6.56	0.63	6.72	0.72	-1.56	-1.40	-0.16	-0.09
	No. 100	2.44	2.53	0.38	2.63	0.50	0.09	0.19	-0.10	-0.12
	No. 200	0.81	1.16	0.25	1.28	0.37	0.35	0.47	-0.12	-0.12
Air - %		5.5	4.00	0.97	3.54	0.93	-1.5	-1.96	0.46	0.04
Slump-ins		2.0	1.08	0.60	1.73	0.85	-0.92	-0.27	-0.65	-0.25
Concrete Temperature °F		Not greater than 90	68.2	4.43	65.2	6.79			3.0	-2.36
Air Temperature °F		Not Less than 40	65.6	6.40	66.6	8.89			-1.00	-2.49
28-DAy Compressive			4374.2	601.9	4348.2	639.1			26.0	-38.8

Though the variations in coarse aggregates No. 1 and No. 2 are large, and departures from target value are high, the composite material had closer conformity with the target value. The differences between the arithmetic means and standard deviations, obtained by the two methods of sampling are relatively small (Table 13). This would favor the use of end-product specifications.

CONCLUSIONS

I. The largest part of the variance is due to the production of material (material variance). Sampling variance was the lowest. The larger sizes of aggregate gave larger variances in comparison with the aggregates of smaller size.

II. In general the larger the fraction of aggregate retained on any particular screen, the larger the variance.

III. The sample size for 2" aggregates needs to be larger than called for in the specifications, in order to reduce the high testing variances.

IV. The variances obtained on the percent passing basis have a considerable effect on the variances of subsequent sieves. The variances obtained on the percent retained basis have a smaller effect. A study of both variances gives the underlying cause of variation.

V. The use of normal distribution with reference to aggregates could result in serious error in the determination of percent defective. The values of skewness and kurtosis should be considered in order to know the real nature of the distribution.

VI. Frequency distributions of aggregates are generally not normal. They also have effects of truncation.

VII. Standard deviation is a measure of the construction process. Aggregate specifications should be based on the fraction retained on each screen, rather than the percent passing basis.

VIII. The variability of aggregates is largely dependent on the proportion of the fraction retained on each individual screen.

IX. Though the variances of the coarse aggregates were large, the total composite aggregate had smaller variability, suggesting the use of end-product specifications.

X. The properties of portland cement concrete give good correlation with normal distribution. The variability of concrete with random sampling as compared to representative sampling is of a random nature. There can be large differences between arithmetic means and standard deviations, depending on the construction process.

XI. The study of historical data gives a wide range of statistics for aggregate and concrete properties. The use of these statistics in the preparation of project specifications, calls for a knowledge of the capability of each construction process.

XII. The value of conformal index is a measure of capability of the construction process to adhere to the job-mix formula. It is unlike the standard deviation which gives a measure of the deviations from the mean of the construction process. It needs to be studied in conjunction with standard deviation, target value, and the specification limits.

XIII. In the comparison of aggregate gradations of the material mixed and the product obtained, the study of matched-pairs indicates low probability of agreement.

XIV. If a minimum thickness of concrete pavement of 8" is desired, an average of 8.4" will have to used for the purposes of estimating the total volume of concrete.

XV. The cost of a research of this type came to 37.1 cents per square yard of concrete pavement placed, of which 72.7% is the cost of labor.

RECOMMENDATIONS

I. An investigation in regard to sample size for large-sized aggregates should be undertaken, in order to obtain the optimum sample size.

II. Specifications for aggregate should be based on percent retained on a particular sieve, rather than percent passing.

III. The validity of normal distribution with reference to aggregate gradation needs complete investigation, and further research should be undertaken.

IV. The wide range of statistics obtained on different projects calls for a study of the process capability of different contractors, equipment and material sources, so that the underlying causes of variation can be established.

V. In view of the small probability obtained with reference to matched-pairs of the product at the concrete mixer and the product obtained in the pavement, adequate data should be obtained, in order to make a valid judgement.

VI. Since an additional 5% of volume of concrete is required for concrete pavement, this additional volume of concrete should be taken into consideration for estimating the cost of highways.

IMPLEMENTATION STATEMENT

It is the feeling of the operational branch which conducted the research that the Arizona Department of Transportation is in a position to initiate selected activities as a result of the findings of this research. The proper timing to implement these activities will be dependent on furture management considerations.

Certain suggested activities such as those of random sampling, control charts and field training of statistical specification usage have been under way for sometime in relation to the control of asphaltic concrete. This work should be continued in light of proposals to extend the use of statistical specification into areas such as portland cement concrete.

A statistical acceptance sampling plan for portland cement concrete will be developed for consideration as a specification item and as a result larger sample sizes for aggregates used in portland cement concrete pavement will be necessary to improve upon large variances on larger screens.

REFERENCES

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Appendix A

TABLE 1-A

ANALYSIS OF VARIANCE - PERCENT RETAINED

COARSE AGGREGATE #1 - PORTLAND CEMENT CONCRETE PAVEMENT

PROJECT I 17-2 (35)

SIEVE SIZE	RANGE	ARITH. MEAN %	MATERIAL VARIANCE	SAMPLING VARIANCE	TESTING VARIANCE	OVERALL VARIANCE	STANDARD DEVIATION	COEF. OF VARIATION	AVERAGE DEVIATION	SKEWNESS	KURTOSIS	NO. OF SAMPLES
2"	0-11	1.51	1.26	-0.66	3.72	4.32	2.08	138.06	1.64	1.73	6.50	200
1½"	4-43	22.62	37.56	9.42	16.50	63.48	7.97	35.22	6.37	0.11	2.71	200
1"	26-64	51.27	39.03	-0.77	13.03	51.29	7.16	13.97	5.49	-0.88	3.96	200
3/4"	5-35	16.25	45.17	4.14	4.59	53.90	7.34	45.19	5.93	0.72	2.62	200
1/2"	0-12	3.64	5.08	0.54	0.56	6.18	2.49	68.40	1.84	1.43	4.91	200
No. 4	0-11	2.34	4.92	0.65	0.29	5.86	2.42	103.66	1.75	1.81	5.75	200

TABLE 2-A

ANALYSIS OF VARIANCE - PERCENT PASSING

COARSE AGGREGATE #1 - PORTLAND CEMENT CONCRETE PAVEMENT

PROJECT I 17-2 (35)

SIEVE SIZE	RANGE	ARITH. MEAN %	MATERIAL VARIANCE	SAMPLING VARIANCE	TESTING VARIANCE	OVERALL VARIANCE	STANDARD DEVIATION	COEF. OF VARIATION	AVERAGE DEVIATION	SKEWNESS	KURTOSIS	NO. OF SAMPLES
2"	89-100	98.46	1.38	0.29	3.43	5.10	2.26	2.29	1.68	-1.66	6.06	200
1½"	53- 96	75.84	51.20	6.27	19.95	77.42	8.80	11.60	7.06	-0.15	2.70	200
1"	7- 67	24.50	134.60	11.11	10.66	156.37	12.50	50.88	9.64	1.16	4.10	200
3/4"	0- 41	8.33	41.68	4.28	4.53	50.49	7.11	85.30	5.00	2.07	7.49	200
1/2"	0- 31	4.70	20.08	2.96	3.30	26.34	5.13	109.31	3.48	2.42	9.30	200
No. 4	0- 21	2.36	5.56	1.91	2.12	9.59	3.10	131.23	1.88	3.37	16.29	200

TABLE 3-A

ANALYSIS OF VARIANCE - PERCENT RETAINED

COARSE AGGREGATE #2 - PORTLAND CEMENT CONCRETE PAVEMENT

PROJECT I 17-2 (35)

SIEVE SIZE	RANGE	ARITH. MEAN %	MATERIAL VARIANCE	SAMPLING VARIANCE	TESTING VARIANCE	OVERALL VARIANCE	STANDARD DEVIATION	COEF. OF VARIATION	AVERAGE DEVIATION	SKEWNESS	KURTOSIS	NO. OF SAMPLES
1"	1-11	3.43	2.22	0.19	0.99	3.40	1.84	53.80	1.44	1.13	4.57	200
3/4"	9-34	18.83	13.42	4.51	1.86	19.79	4.45	23.64	3.39	0.86	4.20	200
1/2"	23-42	30.51	9.32	1.28	1.72	12.32	3.51	11.51	2.78	0.17	2.90	200
3/8"	12-24	17.22	3.22	0.20	0.65	4.07	2.02	11.72	1.54	0.33	3.29	200
1/4"	9-25	18.18	8.22	2.58	0.50	11.30	3.36	18.49	2.73	-0.34	2.52	200
No. 4	1-12	5.63	5.54	0.52	0.17	6.23	2.50	44.38	2.00	0.52	2.74	200
No. 8	0- 8	3.33	2.60	0.23	0.14	2.97	1.72	51.72	1.43	0.42	2.63	200

TABLE 4-A

ANALYSIS OF VARIANCE - PERCENT PASSING

COARSE AGGREGATE #2 - PORTLAND CEMENT CONCRETE PAVEMENT

PROJECT I 17-2 (35)

SIEVE SIZE	RANGE	ARITH MEAN %	MATERIAL VARIANCE	SAMPLING VARIANCE	TESTING VARIANCE	OVERALL VARIANCE	STANDARD DEVIATION	COEF. OF VARIATION	AVERAGE DEVIATION	SKEWNESS	KURTOSIS	NO. OF SAMPLES
1"	89-99	96.46	2.08	0.50	0.96	3.54	1.88	1.95	1.47	-1.06	4.25	200
3/4"	58-89	77.64	22.45	8.25	2.01	32.71	5.72	7.37	4.33	-0.87	3.96	200
1/2"	25-62	47.13	42.62	11.35	2.17	56.14	7.49	15.90	5.85	-0.57	3.10	200
3/8"	12-44	29.91	38.18	8.38	1.41	47.97	6.93	23.16	5.42	-0.23	2.87	200
1/4"	2-22	11.73	19.85	1.85	0.61	22.31	4.72	40.28	3.85	0.22	2.48	200
No. 4	1-11	6.10	5.33	0.43	0.30	6.06	2.46	40.36	1.99	0.11	2.26	200
No. 8	1- 6	2.77	1.03	0.10	0.11	1.24	1.11	40.19	0.88	0.69	3.44	200

TABLE 5-A

ANALYSIS OF VARIANCE - PERCENT RETAINED

COMPOSITE-COARSE AGGREGATES #1 & #2 - PORTLAND CEMENT CONCRETE PAVEMENT

PROJECT I 17-2 (35)

SIEVE SIZE	RANGE	ARITH. MEAN %	MATERIAL VARIANCE	SAMPLING VARIANCE	TESTING VARIANCE	OVERALL VARIANCE	STANDARD DEVIATION	COEF. OF VARIATION	AVERAGE DEVIATION	SKEWNESS	KURTOSIS	NO. OF SAMPLES
2"	0- 6	0.75	0.31	0.17	0.93	1.41	1.19	157.90	0.82	1.73	6.50	200
1½"	2-22	11.37	9.38	2.22	4.24	15.84	3.98	35.01	3.18	0.11	2.69	200
1"	15-36	27.35	10.61	0.15	3.50	14.26	3.78	13.81	2.86	-0.79	3.81	200
3/4"	9-28	17.53	11.38	1.73	1.61	14.72	3.84	21.89	3.11	0.37	2.58	200
1/2"	13-26	17.07	3.15	0.19	0.61	3.95	1.99	11.65	1.51	0.69	4.32	200
3/8"	6-12	8.61	0.81	0.05	0.16	1.02	1.01	11.72	0.77	0.33	3.29	200
1/4"	5-13	9.09	2.05	0.65	0.12	2.82	1.68	18.49	1.36	-0.32	2.52	200
No. 4	1-10	3.98	3.35	0.40	0.11	3.86	1.97	49.39	1.47	1.08	3.80	200
No. 8	1- 9	2.77	2.00	0.29	0.30	2.59	1.61	58.09	1.19	1.42	5.29	200

TABLE 6-A

ANALYSIS OF VARIANCE - PERCENT PASSING

COMPOSITE-COARSE AGGREGATES #1 & #2 - PORTLAND CEMENT CONCRETE PAVEMENT

PROJECT I 17-2 (35)

SIEVE SIZE	RANGE	ARITH. MEAN %	MATERIAL VARIANCE	SAMPLING VARIANCE	TESTING VARIANCE	OVERALL VARIANCE	STANDARD DEVIATION	COEF. OF VARIATION	AVERAGE DEVIATION	SKEWNESS	KURTOSIS	NO. OF SAMPLES
2"	95-100	99.23	0.35	0.07	0.86	1.28	1.13	1.14	0.84	-1.66	6.06	200
1½"	77- 98	87.86	12.76	1.48	5.10	19.34	4.40	5.00	3.54	-0.15	2.67	200
1"	49- 82	60.52	36.01	3.09	3.07	42.17	6.49	10.73	5.05	1.00	3.74	200
3/4"	30- 59	42.98	20.33	3.57	1.68	25.58	5.06	11.77	3.66	0.50	3.97	200
1/2"	13- 39	25.91	20.12	4.01	1.05	25.18	5.02	19.37	3.89	0.06	3.03	200
3/8"	7- 30	17.30	18.58	3.26	0.83	22.67	4.76	27.52	3.65	0.37	3.07	200
1/4"	2- 22	8.21	12.06	1.43	0.74	14.23	3.77	45.94	2.84	1.00	3.96	200
No. 4	1- 14	4.23	3.02	0.57	0.47	4.06	2.02	47.65	1.48	1.43	6.80	200
No. 8	1- 5	1.46	0.27	0.11	0.05	0.43	0.65	44.79	0.47	1.33	6.74	200

TABLE 7-A

ANALYSIS OF VARIANCE - PERCENT RETAINED

FINE AGGREGATE - PORTLAND CEMENT CONCRETE PAVEMENT

PROJECT I 17-2 (35)

SIEVE SIZE	RANGE	ARITH. MEAN %	MATERIAL VARIANCE	SAMPLING VARIANCE	TESTING VARIANCE	OVERALL VARIANCE	STANDARD DEVIATION	COEF. OF VARIATION	AVERAGE DEVIATION	SKEWNESS	KURTOSIS	NO. OF SAMPLES
No. 4	0- 4	1.77	0.53	-0.01	0.24	0.76	0.87	49.22	0.71	0.41	2.84	200
No. 8	9-22	13.94	5.35	-0.03	1.69	7.01	2.65	18.99	2.10	0.59	3.05	200
No.10	3- 7	5.02	0.37	0.15	0.22	0.74	0.86	17.13	0.62	0.25	2.70	200
No.16	14-22	17.28	1.86	0.35	0.32	2.53	1.59	9.21	1.28	0.27	2.75	200
No.30	21-28	24.43	0.78	0.50	0.68	1.96	1.40	5.73	1.13	0.16	2.93	200
No.40	7-15	11.06	2.63	0.16	0.30	3.09	1.76	15.90	1.40	0.04	2.33	200
No.50	7-14	10.24	2.31	0.14	0.26	2.71	1.65	16.08	1.34	-0.13	2.47	200
No.100	7-12	9.95	1.10	0.08	0.35	1.53	1.24	12.42	0.94	-0.47	2.78	200
No.200	2- 5	3.37	0.13	0.05	0.12	0.30	0.54	16.17	0.50	0.53	2.63	200

TABLE 8-A

ANALYSIS OF VARIANCE - PERCENT PASSING

FINE AGGREGATE - PORTLAND CEMENT CONCRETE PAVEMENT

PROJECT I 17-2 (35)

SIEVE SIZE	RANGE	ARITH MEAN %	MATERIAL VARIANCE	SAMPLING VARIANCE	TESTING VARIANCE	OVERALL VARIANCE	STANDARD DEVIATION	COEF. OF VARIATION	AVERAGE DEVIATION	SKEWNESS	KURTOSIS	NO. OF SAMPLES
No. 4	95-100	98.08	0.66	0.04	0.36	1.06	1.03	1.05	0.76	-0.51	3.04	200
No. 8	75- 90	84.15	8.70	0.01	2.32	11.03	3.32	3.95	2.66	-0.39	2.66	200
No.10	68- 86	79.13	12.51	0.02	3.14	15.67	3.96	5.00	3.18	-0.41	2.67	200
No.16	48- 71	61.85	23.08	0.0	4.08	27.16	5.21	8.43	4.17	-0.44	2.70	200
No.30	27- 45	37.42	15.87	0.37	2.91	19.15	4.38	11.70	3.43	-0.43	2.67	200
No.40	19- 32	26.36	5.97	0.08	1.71	7.76	2.79	10.57	2.20	-0.49	2.84	200
No.50	12- 20	16.13	1.34	0.06	0.87	2.27	1.51	9.35	1.18	-0.11	2.67	200
No.100	4- 9	6.18	0.44	0.03	0.31	0.78	0.88	14.27	0.69	0.22	3.26	200
No.200	1- 4	2.81	0.15	0.01	0.14	0.30	0.55	19.42	0.42	-0.29	3.36	200

TABLE 9-A

ANALYSIS OF VARIANCE - PERCENT RETAINED

COMPOSITE AGGREGATE - PORTLAND CEMENT CONCRETE PAVEMENT

PROJECT I 1 -2 (35)

SIEVE SIZE	RANGE	ARITH. MEAN %	MATERIAL VARIANCE	SAMPLING VARIANCE	TESTING VARIANCE	OVERALL VARIANCE	STANDARD DEVIATION	COEF. OF VARIATION	AVERAGE DEVIATION	SKEWNESS	KURTOSIS	NO. OF SAMPLES
2"	0- 3	0.45	0.11	0.06	0.33	0.50	0.71	157.90	0.49	1.73	6.50	200
1½"	1-13	6.75	3.31	0.78	1.50	5.59	2.36	35.01	1.89	0.11	2.69	200
1"	8-21	16.24	3.75	0.05	1.23	5.03	2.24	13.81	1.70	-0.79	3.81	200
3/4"	5-16	10.41	4.02	0.61	0.57	5.20	2.28	21.89	1.85	0.37	2.58	200
1/2"	7-15	10.14	1.11	0.07	0.21	1.39	1.18	11.65	0.90	0.69	4.32	200
3/8"	4- 7	5.11	0.28	0.02	0.06	0.36	0.60	11.72	0.46	0.33	3.29	200
1/4"	3- 7	5.46	0.70	0.25	0.06	1.01	1.01	18.41	0.82	-0.32	2.49	200
No. 4	1- 6	3.08	1.41	0.14	0.09	1.64	1.28	41.53	1.00	0.83	3.06	200
No. 8	5-13	7.35	2.18	0.05	0.52	2.75	1.66	22.60	1.27	0.99	3.98	200
No.10	2- 4	2.86	0.14	0.04	0.05	0.23	0.48	16.88	0.40	0.10	2.34	200
No.16	6- 9	7.01	0.31	0.06	0.05	0.42	0.67	9.21	0.52	0.27	2.75	200
No.30	9-11	9.91	0.13	0.08	0.11	0.32	0.57	5.73	0.46	0.16	2.93	200
No.40	3- 6	4.49	0.43	0.03	0.05	0.51	0.71	15.90	0.57	0.04	2.33	200
No.50	3- 6	4.15	0.38	0.02	0.05	0.45	0.67	16.08	0.54	-0.13	2.47	200
No.100	3- 5	4.04	0.18	0.01	0.06	0.25	0.50	12.43	0.38	-0.47	2.78	200
No.200	1- 2	1.37	0.02	0.01	0.02	0.05	0.22	16.18	0.20	0.53	2.63	200

TABLE 10-A

ANALYSIS OF VARIANCE - PERCENT PASSING

COMPOSITE AGGREGATE - PORTLAND CEMENT CONCRETE PAVEMENT

PROJECT I 17-2 (35)

SIEVE SIZE	RANGE	ARITH. MEAN %	MATERIAL VARIANCE	SAMPLING VARIANCE	TESTING VARIANCE	OVERALL VARIANCE	STANDARD DEVIATION	COEF. OF VARIATION	AVERAGE DEVIATION	SKEWNESS	KURTOSIS	NO. OF SAMPLES
2"	97-100	99.55	0.11	0.06	0.33	0.50	0.71	0.71	0.49	-1.73	6.50	200
1½"	86- 99	92.80	4.47	0.49	1.84	6.80	2.61	2.81	2.09	-0.17	2.69	200
1"	70- 89	76.56	12.65	1.07	1.10	14.82	3.85	5.03	2.99	1.00	3.75	200
3/4"	58- 76	66.14	7.17	1.22	0.60	8.99	3.00	4.53	2.17	0.51	3.98	200
1/2"	48- 63	56.00	7.12	1.37	0.39	8.88	2.98	5.32	2.31	0.06	3.03	200
3/8"	44- 58	50.89	6.58	1.11	0.30	7.99	2.83	5.56	2.17	0.37	3.06	200
1/4"	41- 53	45.43	4.20	0.52	0.27	4.99	2.23	4.92	1.68	0.99	4.02	200
No. 4	40- 48	42.34	1.01	0.28	0.16	1.45	1.20	2.84	0.88	1.35	7.34	200
No. 8	31- 37	35.00	1.42	0.01	0.40	1.83	1.35	3.87	1.12	-0.33	2.45	200
No.10	28- 35	32.14	2.06	0.01	0.54	2.61	1.62	5.03	1.30	-0.41	2.64	200
No.16	19- 29	25.12	3.80	0.01	0.69	4.50	2.12	8.44	1.70	-0.45	2.68	200
No.30	11- 18	15.21	2.62	0.06	0.49	3.17	1.78	11.71	1.40	-0.43	2.65	200
No.40	8- 13	10.72	0.99	0.01	0.30	1.30	1.14	10.62	0.90	-0.47	2.80	200
No.50	5- 9	6.56	0.23	0.01	0.16	0.40	0.63	9.61	0.49	0.03	2.90	200
No.100	2- 4	2.53	0.08	0.01	0.06	0.15	0.38	15.14	0.29	0.58	4.26	200
No.200	0- 2	1.16	0.03	0.00	0.03	0.06	0.25	21.69	0.17	0.64	6.63	200

TABLE 11-A

ANALYSIS OF VARIANCE - SAND EQUIVALENT

FINE AGGREGATE - PORTLAND CEMENT CONCRETE PAVEMENT

PROJECT I 17-2 (35)

RANGE	ARITH. MEAN %	MATERIAL VARIANCE	SAMPLING VARIANCE	TESTING VARIANCE	OVERALL VARIANCE	STANDARD DEVIATION %	COEF. OF VARIATION %	AVERAGE DEVIATION %	SKEWNESS	KURTOSIS	NO. OF SAMPLES
82-95	87.89	5.43	0.53	1.52	7.49	2.74	3.11	2.18	0.07	2.51	200

TABLE 12-A

ANALYSIS OF VARIANCE

PORTLAND CEMENT CONCRETE PAVEMENT

PROJECT I 17-2 (35)

TYPE OF TEST	RANGE	ARITHMETIC MEAN	MATERIAL VARIANCE	SAMPLING VARIANCE	TESTING VARIANCE	OVERALL VARIANCE	STANDARD DEVIATION	COEF. OF VARIATION	AVERAGE DEVIATION	SKEWNESS	KURTOSIS	NO. OF SAMPLES
Air-%	1.5-7.2	4.0	0.72	0.01	0.20	0.93	0.97	23.8	0.70	0.13	4.00	200
Slump in. cm.	0-3.5 (0-8.89)	1.08 (2.74)	0.31 (1.99)	0.02 (0.13)	0.03 (0.20)	0.36 (2.32)	0.60 (1.52)	54.99	0.45 (1.14)	0.93	5.45	196
Temperature Concrete °F °C	58-78 (14.4-25.6)	68.2 (20.1)	18.0 (5.56)	0.2 (0.06)	1.4 (0.43)	19.6 (6.05)	4.43 (2.46)	6.50 (12.24)	3.60 (2.00)	-0.20	2.48	200
Temperature Air °F °C	45-75 (7.2-23.9)	65.6 (18.7)	40.98 (12.65)	0.0 (0.0)	0.02 (0.0)	41.00 (12.65)	6.40 (3.56)	9.77 (19.04)	5.19 (2.88)	-0.74	3.70	50
Compr. Strength 28 Days PSI N/mm^2	2740-6140 (18.89-42.33)	4374.2 (30.16)	307736.2	-6367.2	60878.3	362247.3	601.9 (4.15)	13.8	474.6 (3.27)	0.24	3.18	200
Concrete Density Lbs/C. Ft. Kg/CM	146.0-158.0 (2339-2531)	150.3 (24.08)	1.21	0.47	1.75	3.43	1.85 (29.63)	1.23	1.37 (21.94)	0.62	4.83	172
Core Length in. cm	8.0-9.2 (20.3-23.4)	8.39 (21.31)				0.07	0.26 (0.66)	3.05	0.19 (0.48)	1.09	4.08	48
Core Strength 28 Days PSI N/mm^2	2475-5670 (17.06-39.09)	3747.1 (25.84)				355912.5	596.6 (4.11)	15.9	463.9 (3.20)	0.58	3.87	50

TABLE 13-A

RESULTS OF STATISTICAL ANALYSIS

COMPOSITE AGGREGATE - PERCENT RETAINED
FOR PORTLAND CEMENT CONCRETE - CLASS A

I 10-1 (35) BRENDA - HOPE TI

SIEVE SIZE	RANGE	ARITHMETIC MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	SKEWNESS	KURTOSIS	AVERAGE DEVIATION	NUMBER OF SAMPLES
3/4"	2-11	7.52	1.79	23.88	-0.02	3.21	1.43	64
1/2"	16-35	24.19	2.90	12.00	0.32	5.48	2.06	64
3/8"	10-17	13.99	1.47	10.56	-0.27	3.04	1.14	64
1/4"	4-14	9.12	2.13	23.44	0.26	3.26	1.62	64
No. 4	0- 3	1.16	0.57	49.64	0.84	3.20	0.45	64
No. 8	8-12	9.30	0.81	8.73	1.07	4.22	0.60	64
No. 16	9-13	11.91	0.61	5.15	-2.32	13.47	0.61	64
No. 30	5-11	9.24	0.61	6.66	-4.15	30.42	0.32	64
No. 50	6- 7	6.74	0.30	4.57	0.20	2.78	0.27	64
No. 100	3- 8	4.25	0.65	15.47	3.42	22.70	0.39	64
No. 200	1- 2	1.48	0.35	23.85	-0.01	2.52	0.30	64

TABLE 14-A

RESULTS OF STATISTICAL ANALYSIS

COMPOSITE AGGREGATE - PERCENT RETAINED
FOR PORTLAND CEMENT CONCRETE - CLASS A

I 10-2 (18) EHRENBERG - PHOENIX HWY (YUMA CO LN - BURNT WELL)

SIEVE SIZE	RANGE	ARITHMETIC MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	SKEWNESS	KURTOSIS	AVERAGE DEVIATION	NUMBER OF SAMPLES
3/4"	4-12	7.61	1.81	23.81	0.42	3.29	1.31	49
1/2"	21-29	25.62	2.08	8.11	-0.03	2.26	1.68	49
3/8"	9-16	13.04	1.69	12.95	-0.34	3.00	1.29	49
No. 4	5-14	9.35	2.14	22.93	-0.41	2.81	1.59	49
No. 8	5- 9	6.80	0.87	12.90	-0.14	2.62	0.69	49
No. 16	7-11	9.44	0.76	8.11	-0.93	4.79	0.58	49
No. 30	10-12	10.53	0.47	4.51	-0.05	2.10	0.40	49
No. 50	9-13	10.88	0.72	6.63	-0.22	3.07	0.56	49
No. 100	3- 6	4.57	0.62	13.69	-0.41	2.28	0.51	49
No. 200	0- 2	1.06	0.33	31.43	0.54	4.42	0.27	49

TABLE 15-A

RESULTS OF STATISTICAL ANALYSIS

COMPOSITE AGGREGATE - PERCENT RETAINED
FOR PORTLAND CEMENT CONCRETE - CLASS A

I 10-2 (19) EHRENBERG - PHOENIX HWY (BURNT WELL - TONOPAH)

SIEVE SIZE	RANGE	ARITHMETIC MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	SKEWNESS	KURTOSIS	AVERAGE DEVIATION	NUMBER OF SAMPLES
3/4"	6-10	7.62	0.99	13.04	0.24	2.70	0.80	66
1/2"	21-30	25.47	1.79	7.05	-0.12	2.58	1.43	66
3/8"	11-19	13.47	1.23	9.17	1.22	7.34	0.89	66
No. 4	6-13	9.12	1.24	13.63	0.25	3.49	0.96	66
No. 8	5- 9	6.97	0.97	13.99	0.28	2.38	0.80	66
No. 16	6-11	9.34	1.09	11.71	-1.52	5.37	0.75	66
No. 30	10-12	10.65	0.41	3.86	0.22	3.52	0.30	66
No. 50	9-14	10.68	0.97	9.08	1.30	6.26	0.69	66
No. 100	3- 6	4.61	0.62	13.63	-0.65	2.78	0.51	66
No. 200	0- 2	1.10	0.29	26.49	0.01	2.79	0.26	66

TABLE 16-A

RESULTS OF STATISTICAL ANALYSIS

COMPOSITE AGGREGATE - PERCENT RETAINED
FOR PORTLAND CEMENT CONCRETE - CLASS A

I 17-2 (35) MUNDS PARK - FLAGSTAFF AIRPORT HWY

SIEVE SIZE	RANGE	ARITHMETIC MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	SKEWNESS	KURTOSIS	AVERAGE DEVIATION	NUMBER OF SAMPLES
1/2"	23-50	37.30	6.07	16.27	-0.23	3.05	4.63	53
No. 4	7-39	18.83	6.91	36.72	0.76	3.72	5.22	53
No. 16	12-26	16.72	2.49	14.92	1.81	8.46	1.67	53
No. 50	9-24	17.83	2.29	12.86	-1.71	9.67	1.32	53
No. 100	3- 8	5.01	0.98	19.58	0.32	3.06	0.82	53
No. 200	1- 4	2.17	0.63	29.25	0.16	2.77	0.50	53

TABLE 17-A

RESULTS OF STATISTICAL ANALYSIS

COMPOSITE AGGREGATE - PERCENT RETAINED
FOR PORTLAND CEMENT CONCRETE - CLASS A

I 40-1 (20) TOPOCK - KINGMAN HWY (HAVASU TI - FRANCONIA)

SIEVE SIZE	RANGE	ARITHMETIC MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	SKEWNESS	KURTOSIS	AVERAGE DEVIATION	NUMBER OF SAMPLES
1/2"	20-41	30.04	4.55	15.14	0.39	2.83	3.57	49
No. 4	14-38	27.79	5.40	19.43	-0.71	3.00	4.27	49
No. 16	10-20	14.97	2.27	15.20	-0.27	2.73	1.78	49
No. 50	14-22	17.91	1.88	10.50	0.15	2.96	1.38	49
No. 100	5-10	5.64	0.92	16.46	2.58	11.46	0.59	49
No. 200	1- 2	1.53	0.29	19.09	0.07	2.57	0.24	49

TABLE 18-A

RESULTS OF STATISTICAL ANALYSIS

COMPOSITE AGGREGATE - PERCENT RETAINED
FOR PORTLAND CEMENT CONCRETE - CLASS A

I 40-2 (59) KINGMAN - ASHFORK HWY (JUNIPER MOUNTAIN - CHINO)

SIEVE SIZE	RANGE	ARITHMETIC MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	SKEWNESS	KURTOSIS	AVERAGE DEVIATION	NUMBER OF SAMPLES
1/2"	25-40	30.39	4.29	14.13	0.37	2.23	3.53	41
No. 4	18-30	25.03	3.53	14.13	-0.51	2.04	3.03	41
No. 16	14-20	17.52	1.56	8.92	0.01	2.70	1.21	41
No. 50	18-23	20.35	1.12	5.54	0.23	3.92	0.81	41
No. 100	2- 5	3.47	0.61	17.55	-0.00	2.47	0.47	41
No. 200	0- 1	0.86	0.25	28.99	-0.14	2.78	0.15	41

TABLE 19-A

RESULTS OF STATISTICAL ANALYSIS

COMPOSITE AGGREGATE - PERCENT RETAINED
FOR PORTLAND CEMENT CONCRETE - CLASS A

F 022-3-513 PHOENIX - GLOBE HWY (MESA DRIVE - LINDSAY ROAD)

SIEVE SIZE	RANGE	ARITHMETIC MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	SKEWNESS	KURTOSIS	AVERAGE DEVIATION	NUMBER OF SAMPLES
3/4"	2-16	8.61	2.30	26.75	0.42	4.00	1.75	141
1/2"	16-37	28.80	3.48	12.10	-0.38	3.81	2.71	141
3/8"	5-24	12.85	2.32	18.06	0.50	6.45	1.74	141
No. 4	0-20	7.51	3.57	47.62	0.65	3.68	2.81	141
No. 8	3- 9	5.32	0.79	14.98	0.43	4.24	0.62	141
No. 16	5-10	7.05	0.93	13.29	0.62	3.52	0.73	141
No. 30	5-18	11.10	1.20	10.84	0.16	11.47	0.81	141
No. 50	3-16	9.97	1.33	13.33	-0.38	8.72	0.92	141
No. 100	3-10	5.95	1.19	20.11	0.70	3.61	0.93	141
No. 200	0- 4	1.75	0.59	33.97	0.97	4.95	0.45	141

TABLE 20-A

RESULTS OF STATISTICAL ANALYSIS

COMPOSITE AGGREGATE - PERCENT RETAINED
FOR PORTLAND CEMENT CONCRETE - CLASS A

EHS-T 980 (22) PHOENIX METROPOLITAN AREA (16TH ST. & NORTHERN)

SIEVE SIZE	RANGE	ARITHMETIC MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	SKEWNESS	KURTOSIS	AVERAGE DEVIATION	NUMBER OF SAMPLES
3/4"	5-12	8.94	1.50	16.78	-0.36	2.58	1.25	41
1/2"	20-37	29.04	4.14	14.27	-0.47	2.75	3.12	41
3/8"	8-16	12.59	2.06	16.35	-0.08	2.37	1.67	41
1/4"	1-14	6.19	3.60	58.11	0.51	2.42	2.79	41
No. 4	0- 1	0.44	0.30	67.12	2.24	5.34	0.16	41
No. 8	4- 7	5.27	0.74	14.09	0.24	1.93	0.63	41
No. 16	5- 9	6.90	0.98	14.25	0.62	2.91	0.77	41
No. 30	9-13	11.22	1.02	9.15	-0.21	2.79	0.79	41
No. 50	8-13	10.53	1.15	10.95	-0.32	2.48	0.97	41
No. 100	3- 9	6.30	1.29	20.58	0.29	2.74	1.04	41
No. 200	0- 2	1.55	0.48	30.85	-0.29	2.29	0.40	41

TABLE 21-A

RESULTS OF STATISTICAL ANALYSIS

COMPOSITE AGGREGATE - PERCENT RETAINED
FOR PORTLAND CEMENT CONCRETE - CLASS A

BR-S 371 (5) BUCKEYE - PHOENIX HWY (AGUA FRIA RIVER BRIDGE)

SIEVE SIZE	RANGE	ARITHMETIC MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	SKEWNESS	KURTOSIS	AVERAGE DEVIATION	NUMBER OF SAMPLES
3/4"	6-19	9.96	2.34	23.48	1.13	5.51	1.77	60
1/2"	21-30	25.60	2.01	7.88	-0.37	2.63	1.58	60
3/8"	9-17	13.18	2.01	15.26	0.08	2.37	1.64	60
No. 4	3-10	6.27	1.37	21.99	0.29	5.01	0.97	60
No. 8	1- 9	5.44	0.89	16.38	-0.71	19.04	0.43	60
No. 16	4-14	9.22	1.08	11.72	-0.13	15.79	0.55	60
No. 30	11-17	12.30	0.85	6.97	1.94	12.88	0.58	60
No. 50	7-13	10.96	0.96	8.80	-0.91	5.15	0.76	60
No. 100	4- 6	4.84	0.47	9.91	-0.03	2.34	0.39	60
No. 200	0- 2	1.05	0.25	24.05	0.64	3.01	0.22	60

TABLE 22-A

RESULTS OF STATISTICAL ANALYSIS

COMPOSITE AGGREGATE - PERCENT RETAINED
FOR PORTLAND CEMENT CONCRETE - CLASS D

BR-S 371 (5) BUCKEYE - PHOENIX HWY (AGUA FIRA RIVER BRIDGE)

SIEVE SIZE	RANGE	ARITHMETIC MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	SKEWNESS	KURTOSIS	AVERAGE DEVIATION	NUMBER OF SAMPLES
3/4"	6-19	9.96	2.45	24.59	1.16	5.52	1.79	36
1/2"	21-29	25.74	1.82	7.07	-0.28	3.37	1.36	36
3/8"	10-17	13.46	1.79	13.29	0.04	3.04	1.32	36
No. 4	5-12	6.59	1.37	20.89	2.08	9.57	0.94	36
No. 8	5- 6	5.51	0.48	8.77	0.05	2.02	0.41	36
No. 16	8-10	9.13	0.46	5.04	-0.06	2.67	0.37	36
No. 30	11-13	11.82	0.41	3.48	-0.20	2.37	0.30	36
No. 50	9-12	10.74	0.64	5.97	-0.40	3.30	0.49	36
No. 100	4- 6	4.79	0.39	8.19	0.22	3.14	0.26	36
No. 200	0- 2	1.09	0.28	26.18	-0.39	2.82	0.25	36

TABLE 23-A

RESULTS OF STATISTICAL ANALYSIS

COMPOSITE AGGREGATE - PERCENT PASSING
FOR PORTLAND CEMENT CONCRETE - CLASS A

I 10-1 (35) BRENDA - HOPE TI

SIEVE SIZE	RANGE	ARITHMETIC MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	SKEWNESS	KURTOSIS	AVERAGE DEVIATION	NUMBER OF SAMPLES
3/4"	89-98	92.47	1.79	1.94	0.02	3.21	1.43	64
1/2"	59-77	68.27	3.45	5.06	0.20	3.34	2.66	64
3/8"	47-63	54.28	2.84	5.24	0.47	3.66	2.19	64
1/4"	44-49	45.15	0.95	2.10	1.17	4.92	0.69	64
No. 4	43-46	43.99	0.50	1.15	0.93	4.41	0.38	64
No. 8	33-36	34.69	0.70	2.02	-0.53	3.07	0.56	64
No. 16	20-24	22.78	0.83	3.67	-0.33	2.93	0.66	64
No. 30	11-17	13.54	0.99	7.35	0.36	4.28	0.75	64
No. 50	5-11	6.80	0.89	13.22	0.90	6.08	0.66	64
No. 100	1- 4	2.54	0.50	19.83	-0.10	2.57	0.40	64
No. 200	0- 2	1.06	0.34	32.64	0. 11	3.63	0.27	64

TABLE 24-A

RESULTS OF STATISTICAL ANALYSIS

COMPOSITE AGGREGATE - PERCENT PASSING
FOR PORTLAND CEMENT CONCRETE - CLASS A

I 10-2 (18) EHRENBERG - PHOENIX HWY (YUMA CO LN - BURNT WELL)

SIEVE SIZE	RANGE	ARITHMETIC MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	SKEWNESS	KURTOSIS	AVERAGE DEVIATION	NUMBER OF SAMPLES
3/4"	88-96	92.38	1.81	1.96	-0.42	3.29	1.31	49
1/2"	59-72	66.76	3.37	5.06	-0.46	2.45	2.71	49
3/8"	48-58	53.71	2.22	4.13	-0.30	2.89	1.76	49
No. 4	42-47	44.36	1.14	2.57	-0.34	2.50	0.92	49
No. 8	35-40	37.55	1.04	2.78	-0.12	2.24	0.87	49
No. 16	26-32	28.11	1.14	4.07	0.12	3.50	0.87	49
No. 30	15-20	17.57	1.16	6.64	-0.24	2.91	0.89	49
No. 50	5- 8	6.68	0.81	12.19	-0.54	2.47	0.65	49
No. 100	1- 3	2.11	0.40	19.09	-0.31	3.47	0.31	49
No. 200	0- 1	1.05	0.27	25.79	-0.10	2.32	0.22	49